Applying social network analysis to the examination of interruptions in healthcare

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Highlights:

- Simple counts of interruptions may not inform effective interventions
- Social network analysis gives a holistic view of interruptive communication patterns
- Social network analysis was applied to data collected with Dual Perspectives Method
- The combined approach uncovered interruptive patterns between and within disciplines
- Inter-disciplinary dependencies exposed underlying work system design problems

Keywords:

- interruptions
- social network analysis
- sociotechnical systems

Abstract

Examinations of interruptions in healthcare often focus on a single clinical discipline, and solutions are targeted accordingly. This approach does not take into account the inter-disciplinary dependencies and other sociotechnical aspects that make up the healthcare work system, and suggested solutions may not meet the needs of all stakeholders. In this article a sociotechnical systems perspective is used to uncover the interdependencies between 16 unique work roles that result in interruptions in an intensive care unit (ICU). By applying social network analysis techniques to data collected using the Dual Perspectives Method, we identified targeted systems-based interventions that may reduce unnecessary interruptions while avoiding unintended consequences that impose additional burden on ICU staff. The rich insights gained into the interruptive communication patterns in the ICU work system stand in contrast to findings that would have otherwise been obtained by focusing only on a single clinical discipline or a single perspective.

1 Introduction

Interruptions research has largely focused on protecting the work of a single clinical group, and solutions are targeted accordingly. In a previous review we noted that observational fieldwork is predominantly either nursing- or physician-focused (McCurdie et al., 2016), and very few studies combine observations of more than one role. Commonly, the basis for decisions to intervene are studies that count the rates per hour of interruptions received by a single discipline, where interruptions are categorized by source and/or type (Dante et al., 2016; Duruk, 2015; Kosits and Jones, 2011; McGillis Hall et al., 2010; Redding and Robinson, 2009). Although a single-discipline approach may be informative for a particular group of clinicians, it does not take into account the inter-disciplinary dependencies or other sociotechnical factors that make up the healthcare work system. For this reason, interventions may not always be effective from the perspective of all stakeholders (McCurdie et al., 2017). In this paper we apply a systems approach to the study and treatment of interruptions in order to identify systems-based interventions that may reduce unnecessary interruptions while at the same time avoiding unintended consequences that may impose additional burden on the ICU work system.

A number of researchers have emphasised the importance of a systems approach in the study and treatment of interruptions in healthcare. For example, Werner and Holden (2015, p. 245) note that “a linear one-task-one-person interruption scenario is rarely the case in health care environments”, but instead that multiple tasks occur in parallel involving multiple entities, all of whom can interrupt and be interrupted. The authors extend their view of interruptions to include the impact of higher-level system factors such as organisational culture and policy on lower-level outcomes such as interruption propensity, based on the macroergonomic view of patient safety presented by Karsh and Brown (2010) . Similarly, Weigl et al. (2012) conclude that workflow interruptions can be reduced in healthcare through improved design and consideration of socio-technical aspects such as intra- and inter-professional communication and coordination needs.

Our conjecture is that by analyzing patterns of interaction and interdependencies across *multiple* roles in the intensive care unit (ICU) we may be able to identify vulnerabilities in the work system and infer whether interventions are truly warranted, and in what form. Critically, we conceptualize interruptions as a sociotechnical systems phenomenon where different “work functions”, enacted by people or intelligent agents, sometimes need to interact in order for the work of the unit to get done. Our challenge has been to find a data analysis method that can capture the complexity in the data collected with the Dual Perspectives Method, and that exposes the above interactions in the most effective way. Previously we introduced the Dual Perspectives Method (McCurdie et al., 2017), which we developed in order to collect data about interactions between work functions. In the present paper we introduce social network analysis to interruptions research as a way of providing quantitative measures and strong visualizations of the interactions between work functions. Together, the Dual Perspectives Method and social network analysis reveal patterns of interruptive interactions between work functions and interdependencies between work roles. Such analyses may help researchers determine where the burden of interruptions falls most heavily in the work system, and whether any interventions are warranted to help people handle demands for their time and attention.

Social networks can be constructed from observations of a work system and the resulting models can inform researchers about how work is actually performed (Houghton et al., 2006). Social network models emphasise both (a) functional entities (roles) and (b) the way in which entities are connected (Stanton et al., 2012). Connections between roles can be defined according to chosen parameters (Stanton et al., 2012), including, for our purposes, interruptive communication patterns. The overall network can then be summarised and analyzed mathematically to reveal underlying properties (Houghton et al., 2006; Stanton et al., 2012) such as routines, patterns of coordination, and hierarchical structure. Houghton et al. (2006) note that although the visual representation of the social network graph alone will sometimes be sufficient for making conclusions, mathematical analysis of the network has three key advantages: “First, it helps us to quantify aspects of the network numerically. Secondly, with large or complex datasets it can be used to mine the network dataset for non-obvious features. Thirdly, it can be used to support or reject the analyst’s intuitive reading of the network graph” (pp. 1205-1206). Social network analysis can contribute to optimisation of the entire work system, rather than parts in isolation (Stanton, 2014), contrary to a single clinical discipline approach.

Unlike conventional observation and quantification methods in interruptions research, the combination of the Dual Perspectives Method and social network analysis goes beyond counts of interruptions to a single discipline to uncover patterns of interruptive communication across multiple work roles observed. The purpose of this paper is to present this combination of methods, as well as to provide an account of observational study findings produced using the methods. In the following sections we provide details of the methods used, followed by a presentation of the results. We then draw conclusions from the resulting data to reveal how a single clinical discipline approach could focus our improvement efforts in the wrong place, and to generate interventions that better fit the intended work system. Finally, we highlight lessons learned and share our recommendations for future research in this area.

2 Method

2.1 Setting

This research was conducted in a 30-bed Intensive Care Unit at a large tertiary care hospital in Brisbane, Australia. At the time of this study an average of 25 beds were staffed daily. The physical geography of the unit is arranged according to post-operative (10 beds) and general intensive care needs (20 beds), connected with an adjoining hallway.

2.2 Participants

Invitations to participate in the study were sent to staff in most clinical disciplines and across all operational levels of the ICU, including medical staff, nurses in clinical and non-clinical roles, allied health staff in pre-specified professions, and non-clinical support staff, in order to explore the full range of work coordination needs and motivations for interrupting. Forty-six ‘primary’ participants (P1) across 16 unique ICU roles provided written informed consent and were each directly observed for a minimum duration of three hours. The specific roles and number of participants in each role are shown in Table 1. ‘Secondary’ participants (P2) were staff members whose work intersected with the primary participant’s (P1) work in the form of an interruption.

2.3 Materials and observation procedure

The Dual Perspectives Method (McCurdie et al., 2017) was used to conduct the observations. To summarise, two observers shadowed each primary participant (P1) for at least three hours. The participant’s activities were recorded using custom data collection notebooks with predefined questions and response categories and an audio recorder. An interruption was defined as a diversion of attention away from the participant’s task, briefly or for an extended amount of time, due to an attention request from an external source (e.g., colleague, phone, device), that may or may not have resulted in switching to a new task. When an interruption occurred, both observers independently recorded the details, including the role of the interrupter (P2), a description of the interruption, and the interrupter’s task that could not be completed without the interruption. Some interruptions meeting pre-specified criteria were followed up in more detail to capture the perspectives of both interrupter (P2) and interruptee (P1) on the reason and need for the interruption, along with their ideas about possible interventions. The interrupter (P2) provided verbal consent if they agreed to answer these questions immediately after the interruption took place. These details helped us to interpret the patterns of communication between roles and reasons for interruptions. Further details about the method can be found in the Appendix.

2.4 Social Network Analysis

Notes and recordings from each observation were transcribed and coded. The average number of interruptions received from colleagues (P2) in the 16 unique roles was calculated on an hourly basis. These data were then used to create an “association matrix”, quantifying relationships between roles formed as a result of interruptions. The association matrix was then used to construct a social network graph “from which one can readily observe structures and relationships.” (Houghton et al., 2006, p. 1205). The social network graph was created using Gephi (v0.9.1), an open-source network visualization platform (Bastian et al., 2009). Gephi was also used to run various statistical analyses on the network data, described in Table 3. These social network metrics are applied to individual roles as well as the overall network as a whole (Stanton et al., 2012) to help to uncover non-obvious features of the network, as well as support or reject conclusions based on the visualizations alone (Houghton et al., 2006). The metrics lead to a better understanding of patterns of interaction across *all* roles in the ICU and make it easier to identify vulnerabilities in the work system. By quantifying aspects of the ICU interruptions network numerically, the metrics can also be used for comparisons to other networks or the same network at a different point in time.

3 Results

A total of 962 interruptions to the primary participants (P1) were recorded from all sources (i.e., colleagues, patients, families, alarms, phone calls, etc.). On average, ICU staff received seven interruptions per hour (7.0/h). The In-Charge Nurse role was the most frequently interrupted (11.8/h), and the Pharmacist role was the least frequently interrupted (4.3/h). See Figure 1 for the full list of roles and average number of interruptions received per hour from all sources. If only the findings above were considered, we might be tempted to focus solely on reducing interruptions to the In-

Charge Nurse. As the results below will show, however, there is more to consider when developing interventions that best fit clinical workflow.

3.1 Social network analysis

To analyze the relationships between roles in the network and how closely associated they are to each other, we start with an association matrix shown in Table 1. The association matrix includes only interruptions observed between the 16 unique ICU roles (n=592); interruptions from other sources such as phones, devices, patients and families are not included in the matrix. As is evident in the matrix, the Bedside Nurse role was observed interrupting every other role in the ICU, and frequently initiated the most interruptions.

To visualize the relationships depicted in the association matrix, a weighted, directed, social network diagram was created in Gephi (see Figure 2). To enhance the visualization, a “Force Atlas” spatial layout algorithm was applied to the data[1]. Force directed graph algorithms apply forces of gravity, attraction and repulsion to roles within a network, based on the strength of their relationships to others (Brandes, 2001). Roles that are not connected through interruptions will be placed farther apart in the graph, while roles that frequently interrupt will be drawn closer together. This means that roles with the most interruptions between them are more central in the visualization. Gephi graphical convention uses curved edges in a clockwise orientation to show the direction of communication, or interruptions, between roles. Connecting edges between roles reflect the average number of interruptions calculated on an hourly basis. The colour of the role nodes reflects which of the three ‘communities’ the role belongs to, identified using the Modularity statistics feature in Gephi (Blondel et al., 2008), further described in Table 3 and below. The colour of the connecting edges between roles is a blend of the colours of the two roles linked by that edge.

The ICU social network diagram shown in Figure 2 highlights the many inter-disciplinary dependencies observed in the ICU in which interruptions played a necessary role in order for work to continue. An initial reading of the graph indicates that there were key areas of dependency between the Bedside Nurse, Team Leader, ACCESS (Assistance, Coordination, Contingency, Education, Supervision, Support) Nurse, and In-Charge Nurse roles; these dependencies are potential focal points for intervention. To quantify the underlying properties of the network, mathematical analyses were conducted on the association matrix data shown in Table 1, according to the individual node and global network metrics defined in Table 3.

3.1.1 Individual node metrics

The in-degree, standardised in-degree, out-degree, and standardised out-degree represent the number of ICU roles that interrupt and are interrupted by the target role (see Table 3). These metrics highlight the connectedness of the Bedside Nurse role to all others in the network; the Bedside Nurse interrupted 100% of roles in network and was interrupted by 69% of the roles in the network. The weighted in-degree and weighted out-degree metrics reflect the sum of the average incoming and outgoing interruption volume from all roles in the network. The highest weighted in-degree values were calculated for the In-Charge Nurse role (6.7), followed by the Team Leader (6.6)

[1] Gephi Force Atlas settings: Inertia: 0.1, Repulsion strength: 30000, Attraction strength: 10, Gravity: 30.

and ACCESS Nurse (5.5). The highest weighted out-degree value was calculated for the Bedside Nurse (26.3), who initiated the most interruptions.

These metrics confirm the patterns identified on the ICU social network diagram (Figure 2). The Dual Perspectives Method uncovered that the Bedside Nurse role interrupted the In-Charge Nurse, Team Leader and ACCESS Nurse roles primarily for reasons related to medication administration. Participants revealed that the In-Charge Nurse and Team Leader roles were the sole physical key holders to the restricted drugs cupboard; the Bedside Nurse was unable to access restricted drugs without a physical key and was required to locate someone in the In-Charge or Team Leader role in order to administer these medications, or ask for help to do so from the ACCESS Nurse.

Sociometric status reflects the sum of all incoming and outgoing interruption volume for a particular role, relative to all other roles in the network. Consistent with the metrics above, the Bedside Nurse had the highest sociometric status (1.9); the Administrative Officer and Pharmacist roles were tied for the lowest sociometric status (0.2). Another individual node metric that considers the overall 'significance' of a role in the network is the generalized in-degree and generalized out-degree centrality, calculated based on the number of roles interrupting the target role, and how frequently. The role exhibiting the highest generalized in-degree role centrality was the Team Leader (6.3) and the highest generalized out-degree role centrality was the Bedside Nurse (33.7).

3.1.2 Global network metrics

Global network metrics quantify the properties of the network as a whole. The network density metric measures the number of connected roles as a fraction of the total possible and is based on a scale of 0 to 1; a result of 1 indicates that all roles in the network are connected through interruptive communications. Network density reveals how distributed interruptive communication patterns are across the network. The resulting network density of the ICU work system was 0.5, indicating that there was a moderate level of inter-disciplinary dependency amongst ICU work roles.

In any given network, nodes that are more densely connected to each other than to the rest of the network are referred to as 'communities'. Modularity is a global metric index that identifies the strength of community structure within a network (Newman and Girvan, 2004). In the context of interruptions, members of a community are more likely to interrupt each other than to interrupt other roles in the network. Modularity is calculated by comparing the number of connections within each community to the number of connections that would occur if the roles were connected at random. High levels of modularity indicate distinct divisions between communities, while low levels of modularity (less than 0.5) indicate that communities within the network partially overlap. The resulting modularity value of the ICU work system was 0.208 (at a resolution of 1). This low level of modularity indicates that the communities identified were likely to overlap and were not definitive. In other words, the network was more likely to consist of a core group of roles that interrupted broadly rather than smaller cliques that only interacted with each other. This is consistent with the network density finding.

Diagrams illustrating the communities identified through modularity are shown in Figure 3 and Figure 4. Consistent with the individual node metric findings above, the largest community within the network consisted mostly of nursing professionals. The disproportionate connection between the

Bedside Nurse role and the In-Charge, Team Leader and ACCESS Nurse roles was evident. A second, smaller community was formed amongst the remaining roles in the network (registrars, physiotherapist and pharmacist). For the most part the interruptions between these roles were consistent with expected clinical practice; however, interruptions between Physiotherapists were disproportionately high. The Dual Perspectives Method revealed that the ICU employed only one full-time Physiotherapist while other physiotherapy staff rotate through the unit and the rest of the hospital on a regular basis. This organisational constraint has led to a reliance on the full-time Physiotherapist who was often asked to confirm treatment plans or answer questions about ICU-specific physiotherapy practice.

The inter-disciplinary interruptive communication patterns between Pharmacist and Junior Registrar were also examined using the Dual Perspectives Method. Participants revealed that while staff in the ICU used electronic patient records, the remainder of the hospital used paper patient records requiring manual transcription of patient discharge summaries by the Junior Registrars. The manual transcription of discharge summaries often occurred during overnight shifts when the unit was less busy but may also have been more prone to error, possibly due to reduced access to ancillary services and/or fatigue (Miller et al., 2010; Ruutiainen et al., 2013). The Pharmacist often discovered these errors during her daily review of discharge summaries, prompting a discussion with the Junior Registrar who was required to amend the records.

4 Discussion

Based on the social network analysis, it is evident that no one role in the study ICU functions in isolation. If we had used the common approach of focusing only on a single discipline, and the interruptions they receive, we may have focused our improvement efforts in the wrong place. For instance, we may have chosen to protect the In-Charge Nurse's work simply because they received the most interruptions. Although that solution may have been appropriate for certain contexts, simply focusing on the In-Charge Nurse role would have obscured the richer insights we gained by considering the interruptive communication patterns between all roles in the ICU work system.

Although our analysis uncovered that some of the interruptive communications observed in the ICU are a necessary feature of clinical workflow, the results also indicate that some disproportionate areas of dependency exist between work roles. Unnecessary interruptions may be evidence of underlying system failures (Rivera, 2014), leading to stress on the work system; for this reason they are focal points for intervention. For example, the Bedside Nurse role was connected to every other role in the ICU network through interruptions, potentially indicating unmet needs or a lack of planning. Given the nature of shift lengths and roster rotations, Bedside Nurses will probably treat a new patient on every shift. The Bedside Nurses' need to frequently interrupt all other roles may originate from a lack of initial familiarization with the patient, which could be improved through standardized communication and planning in coordination with other ICU roles at shift turnover, before the day begins.

The Dual Perspectives Method, combined with social network analysis, allowed us to explore specific areas of dependency between roles so that contributing factors could be identified. The most prominent manifestation of dependency leading to interruptions in the ICU work system under study was between the Bedside Nurse and either the In-Charge Nurse, Team Leader or ACCESS Nurses. Although some amount of work communication and coordination is expected between these roles, the analysis highlighted a disproportionate number of unnecessary interruptions between them due to reliance on a physical key needed for restricted drug administrations. To improve the functioning of the work system, a proxy access swipe card system activated with staff ID cards programmed with relevant permissions or access would remove the need for unnecessary interruptions and improve patient care by eliminating the need for Bedside Nurses to search for, and interrupt, the holder of the physical key to the restricted drugs cupboard.

The social network analysis also revealed that the Physiotherapist role experienced the highest intra-role frequency of interruptions. Input gathered from interrupter (P2) and interruptee (P1) using the Dual Perspectives Method uncovered problems associated with the regular rotation of staff through the unit, leading to a reliance on the ‘lead’ Physiotherapist to confirm treatment plans or answer questions about ICU specific concerns with which the other Physiotherapists were not as familiar. During post-interruption follow up discussions, staff identified a need for a resource outlining common ICU scenarios and other ‘frequently asked questions’ about physiotherapy practice on the unit. This intervention has the potential to reduce unnecessary interruptions and reliance on a single person in the work system.

In a further example of higher-level sociotechnical system factors leading to unnecessary interruptions in the ICU, the hybrid paper/computer records system requires manual transcription of a patient discharge record that sometimes results in errors. Although the Pharmacist may be effective at detecting errors in their review of the discharge summary, the work system is operating inefficiently in its current form and is prone to error. Implementation of an electronic discharge summary could alleviate the unnecessary interruptions and would reduce the potential for error.

For each area of disproportionate dependency between roles identified using social network analysis, the observational records collected with the Dual Perspectives Method made it possible to uncover the sociotechnical system factors encouraging interruptions. The information was then used to identify systems-based interventions rather than person-based interventions that are congruent with clinical workflow (Institute for Safe Medication Practices, 1999). However, identifying system vulnerabilities and relevant solutions using the Dual Perspectives Method and social network analysis is just the first step towards work system improvement. As with any complex sociotechnical system, there may be challenges to overcome before improvement efforts can be realized in healthcare (Dixon-Woods et al., 2012).

4.1 Generalizations and future use of this combined approach

Karsh and Brown (2010) made the case that cross-level variables, such as organisational behaviour and hierarchy, should be used to guide patient safety research in order to prevent interventions that are targeted at a single level of the healthcare delivery system. The combined use of the Dual Perspectives Method and social network analysis helped us to uncover not only the intra- and inter-disciplinary dependencies within the ICU itself, but also some of the higher level sociotechnical aspects of the healthcare organisation that contributed to those dependencies in the form of disproportionate interruptive communication patterns. Although these two methods could be used independently, we gain great leverage by combining them, thereby marrying an analysis method with a data collection method that are mutually appropriate for capturing the complexity of workplace interruptions. These findings provide a better basis for decision-making in contrast to findings that would have otherwise been obtained by focusing only on a single clinical discipline or a single perspective.

By quantifying properties of the ICU interruptions network, the metrics can also be used to make comparisons with other work systems or the same work system at a different point in time. The next step in this programme of research will be to implement the selected system-based interventions, following detailed consultation with unit stakeholders. After implementing the intervention(s), further observations conducted using the Dual Perspectives Method and analyzed using the social network analysis methods will be used to determine if work system performance improved.

4.2 Limitations

Given that social network analysis methods were applied to the study of interruptions for the first time in this paper, some limitations were identified. Because it was not possible to observe every member of the ICU work system simultaneously during an observation, communications were averaged over *all* observations for *all* members of a particular role; this is in contrast to the more commonplace applications of social network analysis where individual agents and their communications are captured during a single event, for example. As with any observational study, it is possible that the presence of the researchers may have affected true interruption rates or natural participant behaviours. Furthermore, only a limited number of participants in each role were followed due to the broad range of ICU roles included in this study. In the interest of capturing the most significant and frequent interruptions to particular roles (identified using the Dual Perspectives Method), we chose to follow some roles more frequently than others. As a result, there is the potential for bias in the outcome of the analysis.

A further potential limitation is that we have not calculated inter-observer reliability on the data collected using the Dual Perspectives Method. Conducting reliability checks in the field would have been impractical as they would have required two observers following the P1 role and a further two observers following the P2 role, making four observers altogether. In addition, post-observation reliability checks would have been limited by the fact that only audio recordings and data collection notebooks were available. However, we did seek to augment reliability of the method through the use of a standardized data collection protocol with predefined coding categories. To answer our research question we prioritized collecting data that were valid for our perspective on interacting work functions. For present purposes we argue it may be more scientifically informative to rely on a valid method executed with moderate reliability than on a less valid method executed with high reliability.

Specific findings regarding key areas of dependency between ICU roles and the development of related interventions may not generalize to other critical care settings due to variations in geographical layout, organisation and hierarchy of ICU work roles, among other potential differences. However, the method detailed herein can be used to identify interdependencies revealed through patterns of interruptions, and to identify targeted solutions that meet the needs of any work system. Furthermore, there are many social network analysis tools that can be used to reach the same result;

the Gephi software package was chosen for this research because it is readily available as an open source tool. Most social network visualization platforms offer settings that can be manipulated depending on the characteristics of a particular data set and ideal visualization settings may vary depending on the work system under study. However, the numerical outcome of social network metrics will remain unchanged, making them ideal for comparisons to other networks or the same network at a different point in time as noted.

5 Conclusion

The connectedness of roles within the ICU network suggests that interruptions and any interventions to reduce or mitigate the effects of interruptions will have an impact on the functioning of the entire work system. For this reason it is necessary to employ a combined sociotechnical systems approach, such as the method described herein, in the examination of interruptions in healthcare. Contrary to a single clinical discipline approach, applying social network analysis methods to the observational data collected using the Dual Perspectives Method helped us to identify the intra- and inter-disciplinary dependencies in the ICU work system, along with the contributing sociotechnical system factors necessary for developing interventions that fit clinical workflow better. Interventions that are system-based instead of person-based may reduce interruptions while at the same time avoiding unintended consequences that impose additional burdens on ICU staff. We hope that other researchers will be able not only to build on our use of the Dual Perspectives Method and social network analysis, but also to take our ideas further, in the quest to find harmony between research questions, research methods, and analytic techniques.

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Table 1: Association matrix showing average number of interruptions observed from colleagues between the 16 unique roles / hour

	Administrative		**Allied Health**		**Medical**			**Nursing Clinical**							**Nursing Administration**	
	AO	ASO	Physio	Pharm	SR	JR	Cons	TL	ICN	CNCC	CNCB	BN	AIN	AN	CNRC	NUM
Number of cases observed	2	1	3	3	3	3	4	3	4	2	2	4	3	3	3	3
Average interruptions received / hour	1.83	4.33	3.67	3.00	3.11	4.44	4.83	6.56	6.75	3.00	3.83	4.67	3.44	5.56	3.67	3.44
FROM/TO	AO	ASO	Physio	Pharm	SR	JR	Cons	TL	ICN	CNCC	CNCB	BN	AIN	AN	CNRC	NUM
Administrative																
Administrative Officer (AO)	0.50	-	-	0.11	0.11	0.11	0.08	0.11	0.33	-	0.33	0.25	-	-	0.11	-
Administrative Support Officer (ASO)	0.17	-	-	-	-	-	-	-	-	0.33	-	-	-	-	0.11	0.78
Allied Health																
Physiotherapist	-	-	**2.44**	0.33	0.11	-	0.08	0.11	0.08	-	-	0.33	0.11	0.11	-	-
Pharmacist	-	-	-	-	0.11	0.33	0.08	-	-	-	0.17	0.08	-	-	-	-
Medical																
Senior Registrar (SR)	-	-	0.11	-	-	0.44	**1.42**	0.11	0.33	-	-	0.08	-	-	-	-
Junior Registrar (JR)	0.17	-	0.22	0.44	0.78	1.00	0.58	-	0.33	-	-	0.25	-	0.11	-	-
Consultant	-	**2.33**	-	0.11	0.33	0.56	0.42	-	0.42	0.33	0.17	0.50	-	-	0.11	-
Nursing Clinical																
Team Leader (TL)	-	-	-	0.11	-	0.11	0.17	-	0.33	0.17	0.50	0.17	-	1.33	-	0.11
In-charge Nurse (ICN)	0.17	-	-	0.11	-	-	0.58	0.89	-	-	0.50	0.33	-	0.33	0.22	-
CNC Clinical (CNCC)	-	0.33	0.11	-	0.11	-	-	0.33	0.33	-	-	-	-	-	0.11	-
CNC Backfill (CNCB)	-	-	0.11	-	-	-	-	-	-	0.17	-	-	-	-	0.11	0.44
Bedside Nurse (BN)	**0.67**	0.67	0.56	**1.78**	**1.44**	**1.78**	1.25	**2.89**	**3.33**	**1.50**	**1.17**	**1.92**	1.56	**3.33**	**1.89**	0.56
Assistant in Nursing (AIN)	-	-	-	-	-	-	-	-	0.17	-	-	0.17	**1.78**	0.11	0.11	-
ACCESS Nurse (AN)	-	-	0.11	-	0.11	0.11	0.17	2.11	0.75	-	0.33	0.58	-	0.22	0.11	-
Nursing Administration																
Clinical Nurse Roster Coordinator (CNCR)	0.17	0.33	-	-	-	-	-	-	0.33	0.50	0.67	-	-	-	-	**1.33**
Nurse Unit Manager (NUM)	-	0.67	-	-	-	-	-	-	-	-	-	-	-	-	0.78	0.22

(CNC: Clinical nurse consultant; ACCESS nurse: Assistance, Coordination, Contingency, Education, Supervision, Support nurse)

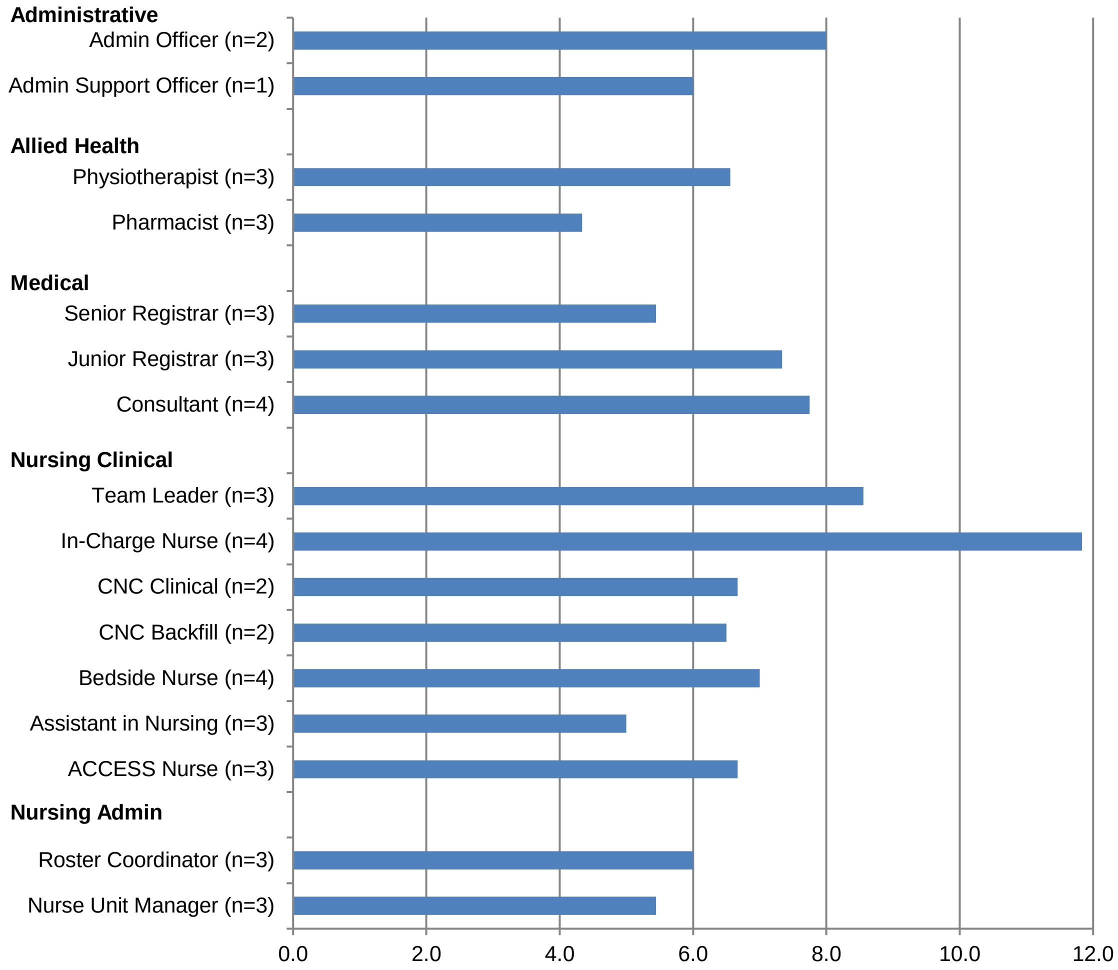


Figure 1: Average number of interruptions received by participants (P1) from all sources (i.e., colleagues, patients, families, alarms, phone calls, etc.) per hour

Table 2: Social network metrics applied to ICU interruptions network

Role	In-degree	Out-degree	Standardized in-degree	Standardized out-degree	Weighted in-degree	Weighted out-degree	Sociometric status	Generalized in-degree role centrality	Generalized out-degree role centrality
	Number of clinical roles that interrupt target clinical role	Number of clinical roles that are interrupted by target clinical role	% of all ICU roles that interrupt target clinical role	% of all ICU roles that are interrupted by the target clinical role	Sum of average incoming interruption volume from all clinical roles	Sum of average outgoing interruption volume from all clinical roles	Sum of all incoming and outgoing interruption volume, relative to all clinical roles	Overall 'significance' of a role, based on how many roles are interrupting, and how frequently	Overall 'significance' of a role, based on how many other roles it interrupts, and how frequently
AO	6	10	38%	63%	1.9	2.0	0.2	1.0	0.9
ASO	5	4	31%	25%	4.3	1.4	0.4	4.0	0.8
Physio	7	9	44%	56%	3.7	3.7	0.5	2.6	2.4
Pharm	7	5	44%	31%	3.0	0.8	0.2	2.0	0.3
SR	8	6	50%	38%	3.1	2.5	0.3	1.9	1.6
JR	8	9	50%	56%	4.4	3.9	0.5	3.3	2.5
Cons	10	10	63%	63%	4.8	5.3	0.6	3.4	3.8
TL	7	9	44%	56%	6.6	3.0	0.6	**6.3**	1.7
ICN	**11**	8	**69%**	50%	**6.7**	3.1	0.6	5.3	2.0
CNCC	6	6	38%	38%	3.0	1.3	0.3	2.1	0.6
CNCB	8	4	50%	25%	3.8	0.8	0.3	2.7	0.4
BN	**11**	**16**	**69%**	**100%**	4.7	**26.3**	**1.9**	3.0	**33.7**
AIN	3	5	19%	31%	3.5	2.3	0.4	3.7	1.6
AN	7	10	44%	63%	5.5	4.6	0.6	4.9	3.1
CNCR	10	6	63%	38%	3.7	3.3	0.4	2.2	2.5
NUM	6	3	38%	19%	3.4	1.7	0.3	2.6	1.2
Means	7.5	7.5	47%	47%	4.1	4.1	0.5	3.2	3.7

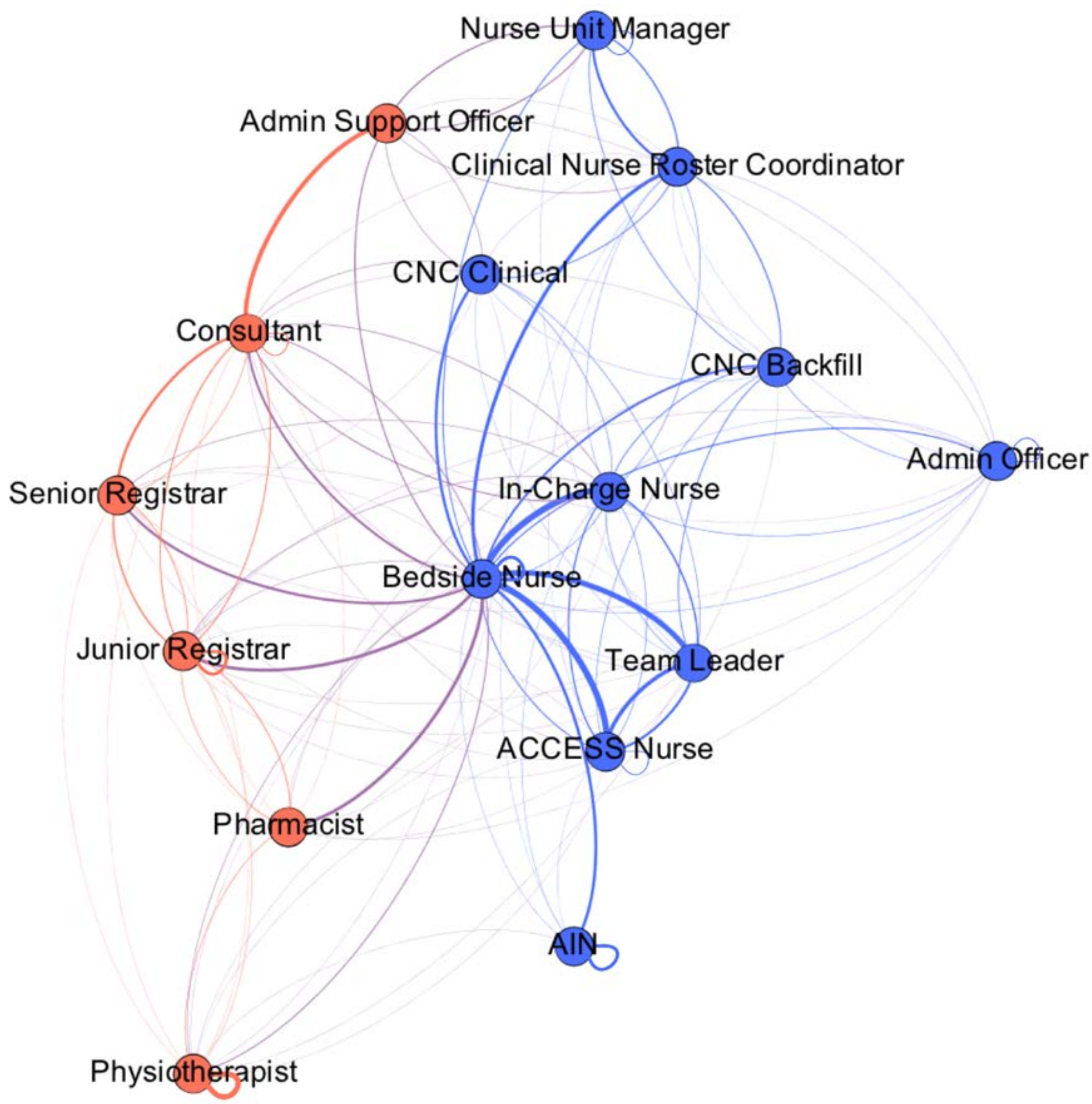


Figure 2: ICU social network diagram

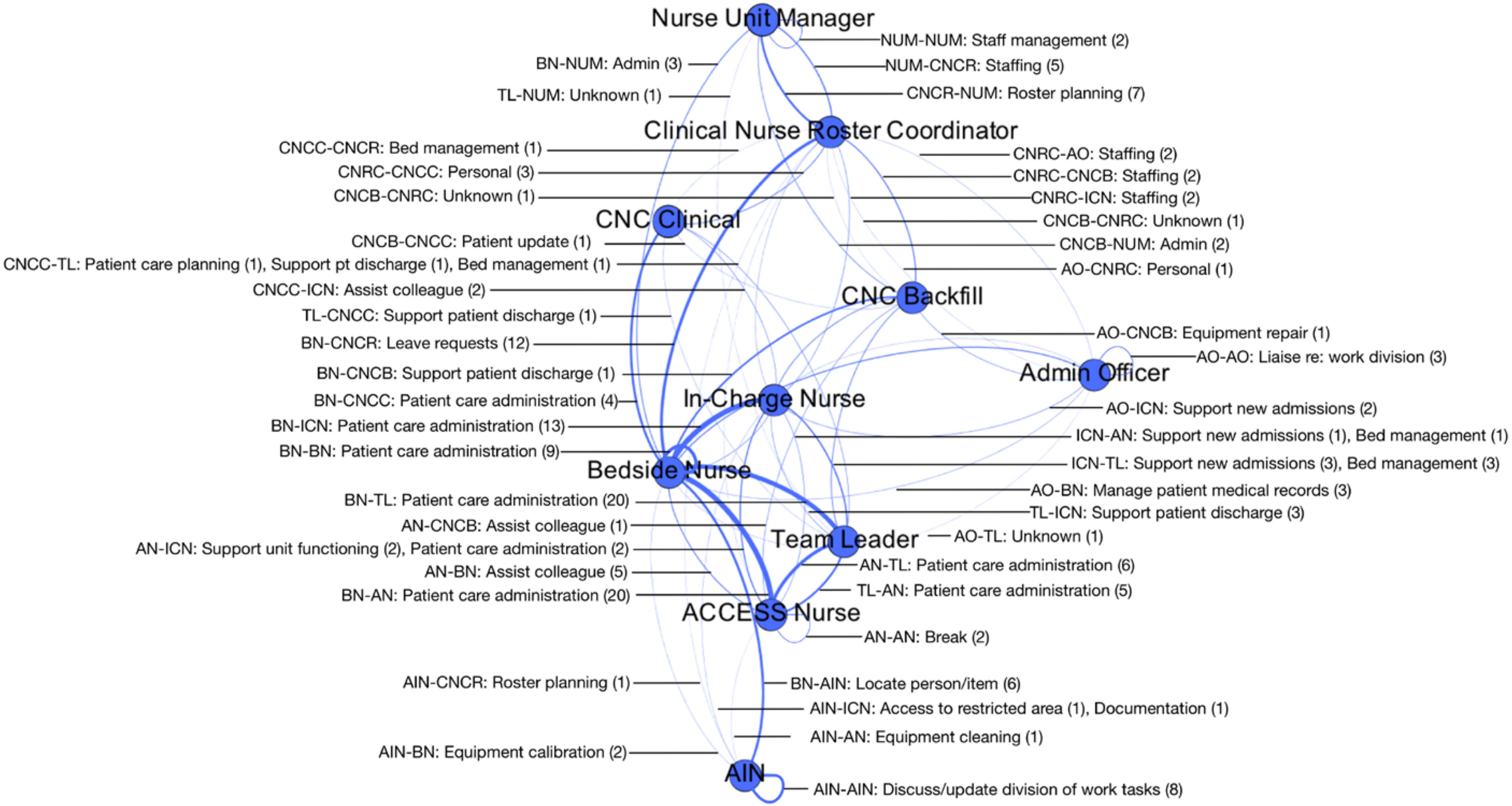


Figure 3: Community of densely connected nodes, identified using modularity metric.

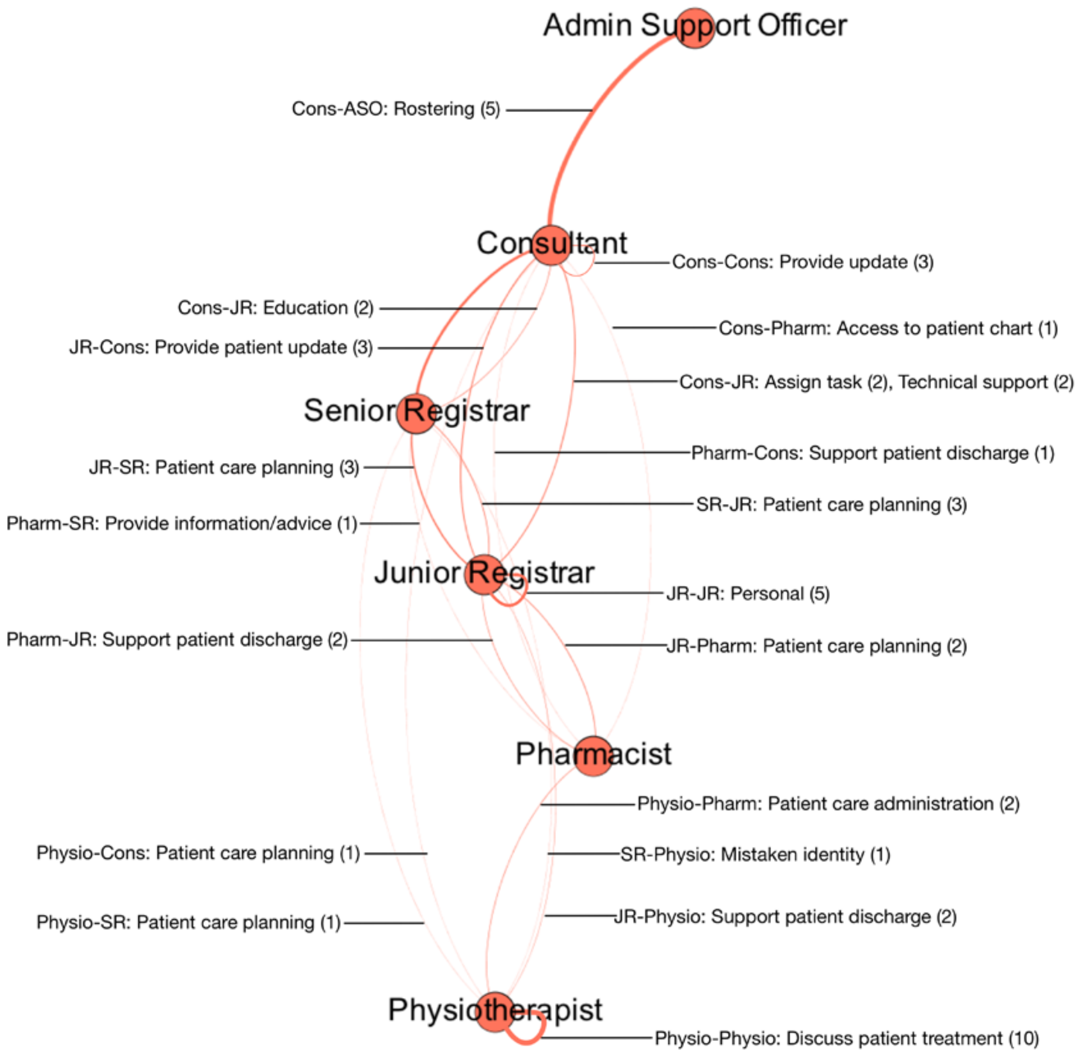
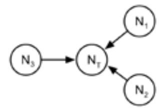
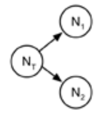
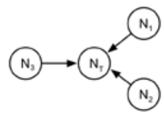
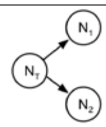
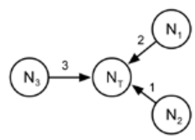
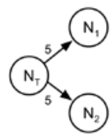
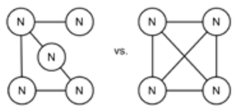
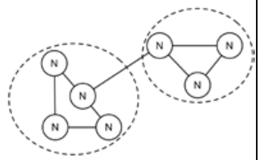


Figure 4: Additional community of densely connected nodes, identified using modularity metric

Table 3: Individual node and global social network analysis metrics, adapted for the interruptions context

Individual node metrics		
Metric	Definition	Illustration
In-degree	The number of roles (nodes) that have interrupted the target role (node N_T). This is an indication of how connected a clinical role is to others in the ICU network through interruptions, regardless of how frequently they occur.	 = 3
Out-degree	The number of roles (nodes) that have been interrupted by the target role (node N_T). This is an indication of how connected a clinical role is to others in the ICU network through interruptions, regardless of how frequently they occur.	 = 2
Standardized in-degree	In-degree count above, expressed as a percentage of the number of nodes in the network. This measure allows us to compare the in-degree of nodes across networks of different sizes or densities.	 ÷ n_{nodes} = 75%
Standardized out-degree	Out-degree count above, expressed as a percentage of the number of nodes in the network. This measure allows us to compare the out-degree of nodes across networks of different sizes or densities.	 ÷ n_{nodes} = 67%
Weighted in-degree	Each node-to-node connection, or 'edge', is weighted according to the average number (frequency) of interruptions observed from one role (node) to another over a 3-hour observation period. The weighted in-degree is the total weight of all incoming edges to a target node, N_T. This is an indication of incoming interruption 'volume' for a particular clinical role.	 = 6
Weighted out-degree	The weighted out-degree is the total weight of all outgoing edges from a target node. This is an indication of outgoing interruption 'volume' for a particular clinical role.	 = 10
Sociometric status	The sum of the adjusted frequency of interruptions received and made by a role (in other words, the sum of the weighted in-degree and out-degree measures above) relative to the total number of roles (n_{nodes}) in the network. This is an indication of *total* incoming and outgoing interruption 'traffic' for a particular clinical role, relative to the total number of roles in the ICU network.	$\frac{\text{(weighted-in degree + weighted out-degree)}}{n_{nodes}}$
Generalized in-degree centrality	A measure of the overall significance of a role (node) in the network as a result of incoming interruptions, based on a combination of in-degree and weighted in-degree measures. To calculate the generalized in-degree centrality, a tuning parameter α is used that controls for the relative importance of its in-degree and weighted in-degree (Opsahl et al., 2010). When the tuning parameter is set to less than 1, the weighted-in degree (or total volume of	$\text{in-degree} \times \left(\frac{\text{weighted-in degree}}{\text{in-degree}}\right)^{\alpha}$

	interruptions) becomes less important and the in-degree (number of connections to other nodes) increases the value of the measure. When the tuning parameter is greater than 1, the in-degree becomes less important and the weighted-in degree increases the value of the measure. In the case of interruptions, the weighted in-degree, or total volume of incoming interruptions, is more important than in-degree because it tells us about the frequency of interruptions; this makes it easies to identify disproportionate areas of dependency between clinical roles. Therefore, a tuning parameter of α = 1.5 has been chosen for the purpose of this research.	
Generalized out-degree centrality	A measure of the overall significance of a role (node) in the network as a result of its outgoing interruptions, based on a combination of out-degree and weighted out-degree.	$\text{out-degree} \times \left(\frac{\text{weighted-out degree}}{\text{out-degree}}\right)^{\alpha}$
Global network metrics		
Metric	Definition	Illustration
Network density	The number of connections between roles as a fraction of the total connections possible. The network density value can range from 0 (no interruptions, or connections, in the network) to 1 (all roles are connected to, or interrupting, others). This doesn't tell us much about the frequency of interruptions, but it does give us a sense of how 'distributed' communication/interruptions are in the ICU network.	
Modularity	In any given network, nodes that are more densely connected to each other than to the rest of the network are referred to as 'communities'. Modularity is an index that identifies the strength of community structure within a network (Newman and Girvan, 2004). In the case of interruptions, members of a community are more likely to interrupt each other than to interrupt other nodes in the network. Modularity is calculated by comparing the number of connections within each community to the number of connections that would occur if the nodes were connected at random. High levels of modularity indicate distinct divisions between communities. Low levels of modularity (less than 0.5) indicate that communities within the network partially overlap. In the latter case, the network is likely to consist of a core group of nodes that do not form distinct communities. https://netlytic.org/home/?page_id=2	

Appendix – Details of the Dual Perspectives Method

Information about the Dual Perspectives Method (DPM) is available in McCurdie et al. (2017) which presented qualitative findings from the method. The following details cover aspects of the DPM that are relevant for the present Social Network Analysis.

Training of observers

Data collection procedures for the DPM were refined following a pilot observation study, and all observers were trained in the data collection method used. Two observers were present at each observational session. Observer A, who followed participant P1 in every observation, had a systems engineering background. Observer B followed participant P2. The role of Observer B was filled by one of three clinical research nurses who had clinical experience in the chosen unit of study. It was important that at least one observer at each observational session was a staff member of the ICU, so that work functions could be more accurately identified as they occurred. The purpose of having two observers from different disciplines was to ensure both a systems perspective on work functions and a valid practitioner viewpoint on how ICU staff enact work functions.

Data collection

Both observers used a customised data collection notebook and an audio recorder during observations. Each notebook contained questions specific to the participant of interest (P1 – interruptee, or P2 – interrupter) and responses were selected mostly from predefined categories. Each booklet contained blank pages for capturing details of the primary participant's work (P1) between interruptions.

Key data collected about P1's work following an interruption (completed by Observer A):

- What was the participant doing when their attention was required?
- Who or what requested their attention?
- What was the content of the request or distraction?

Key questions asked of P2 following an interruption (completed by Observer B):

- Role/scope
- Experience
- What were you doing that you couldn't complete without needing to request the participant's attention?
- Why did you need to request the participant's attention?
- Is there any information/forward planning that may have prevented this attention request? How could the system be rearranged?
- Do you feel that the reason for your attention request has been resolved?

All observations were purposely conducted during day shifts to capture peak activity across the unit.

Session debrief

Following each observation session, the observers conducted a debriefing session with the primary participant (P1). Specifically, for each interruption that was followed up, P1 was asked, "Is there any information/forward planning that may have prevented this attention request?" In this way, both participants' perspectives of the same interruption event were captured, including their perceptions about possible interventions.

Copies of the DPM data collection materials are available from the corresponding author (TMcC) on request.